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ABSTRACT: Most groundfish species managed by the North Pacific Fishery Management Council are closed to directed fishing for a portion of the fishing year for various reasons, the most common being the attainment of the total allowable catch (TAC) or the seasonal allowance of the TAC. Bycatch of non-targeted groundfish species for which directed fishing is closed may be retained in other fisheries up to a maximum retainable bycatch (MRB) level established by regulation as a percentage of the directed catch retained during a fishing trip. For some species, MRB percentages are generously set at levels that exceed "natural" bycatch rates to maximize the opportunity to retain these non-targeted species while reducing overall harvest rates. When the bycatch species is more economically valuable than the target species an incentive exists to "top off" by targeting the bycatch species until the MRB level is attained. We contrast 2 fisheries in which topping-off behavior was previously anecdotally reported. Because of differing species spatial distributions, some rockfish fisheries, *Sebastes* and *Sebastolobus*, in the Gulf of Alaska usually have an observed sablefish *Anoplopoma fimbria* bycatch rate below the prescribed MRB. These natural bycatch rates were estimated based on National Marine Fisheries Service survey and observer program fishery data. The estimated bycatch rates were reasonably precise with most coefficients of variation less than 50% for species of interest. By examining the observed catch from individual trawl hauls in a geographical information system, we were able to demonstrate topping-off behavior with more valuable sablefish in the rockfish fishery. The temporal and spatial targeting patterns of individual vessels were tracked, and distinctive hauls with sablefish as the dominant catch were identified. Similarly, shortraker *Sebastes borealis* and rougheye *S. aleutianus* rockfish are more valuable than Pacific ocean perch *S. alutus* in the Aleutian Islands, and there were anecdotal reports of topping-off with the shortraker–rougheye management complex of rockfish. However, our analysis did not reveal strong evidence of this practice.

INTRODUCTION

Fisheries resources are harvested under a framework of regulations. In addition to seasonal or area-specific guidelines, fishermen are regulated in the amounts and species of fish they are allowed to retain. Because much of the gear used in fishing is not species-specific, a species that cannot be retained due to management restrictions may still be subject to capture by fishing gear. In light of this fact, fishery managers must account for non-targeted catch, attempt to reduce encounters of sensitive or fully allocated species, and make retention allowances so that inadvertently encountered fish are not unnecessarily discarded.

Maximum retainable bycatch (MRB) is used by managers of Alaska's commercial groundfish fisheries to reduce the harvest rate of a species, which is closed to directed fishing, by limiting the amount of that species that may be retained in other directed fisheries. In the course of a fishing trip, the amount of a bycatch species allowed to be retained is equal to a percentage of the directed retained catch by weight. A fishing trip is defined as the period between commencement of fishing and delivery for processing or till the end of a weekly reporting period. For instance, sablefish *Anoplopoma fimbria* are currently allowed an MRB of up to 7% by weight of a trip's retained catch of rockfish, *Sebastes* and *Sebastolobus*, taken in an

Authors: DAVID R. ACKLEY is a fisheries management specialist with the National Marine Fisheries Service, Sustainable Fisheries/Alaska Region, P.O. Box 21668, Juneau, AK 99802. David R. Ackley's email: david.ackley@noaa.gov. JONATHAN HEIFETZ is a fishery research biologist with the National Marine Fisheries Service, Auke Bay Laboratory, 11305 Glacier Highway, Juneau, AK 99801.

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Table 1. Current Gulf of Alaska retainable percentages of bycatch species in rockfish fisheries.

Bycatch Species (%)	Target Species						
	Pacific Ocean Perch	Shortraker/Rougheye Rockfish	Other Slope Rockfish	Northern Rockfish	Pelagic Shelf Rockfish	Demersal Shelf Rockfish	Shortspine Thornyhead
Walleye pollock	20	20	20	20	20	20	20
Pacific cod	20	20	20	20	20	20	20
Deep flatfish	20	20	20	20	20	20	20
Rex sole	20	20	20	20	20	20	20
Flathead sole	20	20	20	20	20	20	20
Shallow flatfish	20	20	20	20	20	20	20
Arrowtooth flounder	35	35	35	35	35	35	35
Sablefish	7	7	7	7	7	7	7
All rockfish	15	15	15	15	15	15	15
Demersal shelf rockfish	1	1	1	1	1	1	1
Atka mackerel	20	20	20	20	20	20	20
Other species	20	20	20	20	20	20	20

open rockfish fishery. Any sablefish caught in excess of this amount must be discarded. Such discards are in contrast to economic discards, which are related to factors such as markets and processing capacity (Pautzke 1996).

The MRB is one of many regulations or operational restrictions enacted by the North Pacific Fishery Management Council (NPFMC) to control bycatch. Seasons, gear restrictions, time and area closures, monitoring, and enforcement play important roles in controlling bycatch (Pautzke 1996; Witherell and Pautzke 1997). The intent is to set MRBs high enough to limit regulatory discards but low enough that they do not provide incentives for seeking out concentrations of restricted species thereby generating undesirably high harvest rates. In practice many MRBs have been widely set across broad categories, generally meeting the above goals without specifying individual fisheries or bycatch species. For instance, MRB rates for many bycatch species in the rockfish fisheries have been established at 20% (Table 1).

In this paper we define the bycatch rates usually seen in the pursuit of directed fishing as natural rates. Cases exist in which the established MRB levels are higher than the natural encounter rates for the bycatch species. In these cases, especially when the bycatch species are more economically valuable than the target species, an incentive exists to maximize the bycatch up to the MRB level. Maximizing the bycatch when the natural bycatch rates are low requires that hauls are made to "top off" the haul with, or specifically target, the bycatch species. Problems occur for fisheries managers when topping-off incentives inadvertently increase the harvest of a bycatch species above the total allowable catch (TAC) or disrupt the prescribed allocation among fisheries. When MRBs are too high, com-

petition for the bycatch species occurs, and managers seek reductions in MRBs to reduce topping off without increasing discards.

Anecdotal reports of topping off sablefish in Gulf of Alaska rockfish fisheries and topping off shortraker *Sebastes borealis* and rougheye *S. aleutianus* rockfish in Pacific ocean perch *S. alutus* and Atka mackerel *Pleurogrammus monopterygius* fisheries in the Aleutian Islands provided the impetus for the analysis presented in this paper. Sablefish and shortraker and rougheye rockfish are economically valuable species, and the incentive to maximize their bycatch amounts is great. In 1996, for example, the average exvessel price for trawl-caught sablefish was \$1.70 per pound, and the average exvessel price for rockfish (all species) was \$0.15 per pound (Kinoshita et al. 1998). The rockfish price per pound is an average of the more valuable rockfish species such as the shortraker-rougheye rockfish complex and the less valuable but more plentiful species such as Pacific ocean perch. In 1996 shortraker-rougheye rockfish had a first wholesale value (exvessel price information was not available) of \$1.10–\$1.80 per pound. However, the amount of these species available as retainable bycatch in non-directed fisheries is limited. Sablefish are currently fully allocated and managed under an individual transferable quota system, and rockfish in the shortraker-rougheye management category have a relatively small TAC, which has been exceeded in recent years. Trawl fisheries in the Gulf of Alaska can retain sablefish only as bycatch, and shortraker and rougheye rockfish are retainable only as bycatch for all gear types in the Aleutian Islands.

The estimated natural bycatch rates of various species, including sablefish, were estimated in the Gulf of Alaska rockfish fisheries (Heifetz and Ackley 1997).

Bycatch of various rockfish species in the Aleutian Islands Pacific ocean perch and Atka mackerel fisheries was presented as part of a NPFMC proposed regulatory change to lower the MRB rate for shortraker–rougheye rockfish in Aleutian Islands fisheries in 1997.

This paper summarizes fisheries information primarily from the rockfish fisheries and provides: estimates of natural bycatch rates based on survey and fishery data, currently established MRB rates, examples of topping off of sablefish in the Gulf of Alaska which are apparent in the data, and examples of topping off of shortraker–rougheye rockfish in the Aleutian Islands not indicated by the data. The natural bycatch rates of individual hauls were examined for patterns in target categories, and topping-off behavior was indicated when hauls generally made in one target category shifted into another category. We emphasize bycatch of sablefish in the Gulf of Alaska because sablefish is a bycatch-only species during the entire year for all trawl fisheries, and we use sablefish as an example of topping-off behavior.

METHODS

Data

Two sources of data used to estimate natural bycatch rates were data from National Marine Fisheries Service (NMFS) triennial trawl surveys for 1990, 1993, and 1996, and fishery data from the NMFS Observer Program for 1994–1996. Although the rates generated from survey data do not necessarily represent normal fleet operations because of possible gear, geographic, and seasonal differences between the survey and the fishery, survey data can supply a fishery-independent estimate of bycatch rates that can be compared to rates determined from the fishery. Fishery data included vessel, haul, and catch information. In the Gulf of Alaska a total of 5,428 hauls were observed in 1994, 7,369 hauls in 1995, and 7,353 hauls in 1996. The observed tonnage in each year represented roughly 39%, 41%, and 53% of the total reported catch in 1994, 1995, and 1996, respectively. In the Aleutian Islands a total of 4,066 hauls were observed in 1995, and 4,931 were observed in 1996.

Assignment of Target Species

We based bycatch rates on the accumulation of the catch by species over all hauls within a target category.

A problem in examining data from the fishery is that more than one species may be a target during a particular time period, and at times even species that are on bycatch-only status may be targeted in a particular haul if the bycatch allowance has not been met.

The first step in the estimation process was to determine the target species in each haul for both the survey and fishery data. Each haul was assigned the NPFMC management category with the highest catch weight. The categories were walleye pollock *Theragra chalcogramma*, Pacific cod *Gadus macrocephalus*, deepwater flatfish, rex sole *Glyptocephalus zachirus*, flathead sole *Hippoglossoides elassodon*, shallow-water flatfish, sablefish, Atka mackerel, and aggregated rockfish (all *Sebastes* and *Sebastolobus* rockfishes). Arrowtooth flounder *Astheresthes stomias* was not included as a category because it is rarely targeted by the commercial fishery, though arrowtooth flounder often dominates the catch of many survey hauls. Analysis of bycatch rates was limited to hauls in which aggregated rockfish was the dominant species group. In total, 187 tows from the 1990 triennial trawl survey, 204 tows from the 1993 survey, and 228 hauls from the 1996 survey were in the rockfish category. These aggregated rockfish hauls were further categorized based on the rockfish management group with the highest catch weight. The categories were Pacific ocean perch, shortraker–rougheye rockfish, other slope rockfish, demersal shelf rockfish, northern rockfish *Sebastes polyspinis*, pelagic shelf rockfish, and shortspine thornyheads *Sebastolobus alascanus*. These secondary targets represent the NPFMC management categories for rockfish. The pelagic shelf rockfish category was comprised almost entirely of dusky rockfish *Sebastes ciliatus*, and the 2 are considered to be synonymous. From the observer data, the demersal shelf rockfish category included only a few hauls and was not examined in detail in this analysis. The number of hauls (n_k) by rockfish category and year from NMFS survey and observer data are summarized in Tables 2 and 3.

In each rockfish category the bycatch rates of non-rockfish species and other rockfish species were examined as well as the bycatch rate of aggregated rockfish, which was defined as total rockfish minus the weight of the target rockfish species. For example, in the pelagic shelf rockfish category the bycatch rates of non-rockfish species, Pacific ocean perch, northern rockfish, shortspine thornyheads, shortraker–rougheye rockfish, demersal shelf rockfish, and other slope rockfish were examined as well as the bycatch rate of all rockfish combined minus the target species weight, in this case, pelagic shelf rockfish.

Table 2. Estimated natural bycatch rates in Gulf of Alaska rockfish fisheries based on survey data.

Target Species	Bycatch Species	Bycatch Rate (%)			Coefficient of Variation (%)		
		1990	1993	1996	1990	1993	1996
Northern rockfish	Pacific ocean perch	6.1	3.6	11.8	52.9	52.3	10.1
	Pelagic shelf rockfish	11.2	12.2	11.5	40.7	46.2	15.3
	Shortspine thornyhead	0.0	0.0	0.0		109.5	27.9
	Shortraker/roughey	0.0	0.0	0.1	66.3	57.3	28.2
	Demersal shelf rockfish	0.1	0.2	0.3	69.7	62.5	27.7
	Other slope rockfish	9.3	2.8	4.6	79.2	45.2	8.4
	Rockfish minus target	27.0	18.7	28.3	23.7	40.9	5.0
	Sablefish	0.4	1.0	0.7	85.7	98.7	27.9
	Pacific cod	2.1	3.7	5.0	64.8	44.5	24.0
	Walleye pollock	0.2	0.8	1.9	94.0	77.9	26.0
	Rex sole	0.8	1.0	1.6	87.3	49.0	27.4
	Flathead sole	0.2	0.4	0.1	79.8	77.1	28.3
	Arrowtooth flounder	5.8	16.4	22.4	63.7	54.9	27.9
	Deepwater flatfish	0.1	0.3	0.9	76.1	56.3	27.5
	Shallow-water flatfish	1.4	0.8	1.9	57.8	49.5	25.5
	Number of Hauls	24	26	28			
Other slope rockfish	Pacific ocean perch	10.6	23.4	13.1	44.9	27.5	19.8
	Northern rockfish	0.4	8.3	0.0	67.7	83.8	26.5
	Pelagic shelf rockfish	7.6	18.8	7.3	62.8	51.7	18.5
	Shortspine thornyhead	1.5	3.6	0.8	52.6	36.1	27.6
	Shortraker/roughey	0.5	0.5	0.7	64.0	62.4	25.4
	Demersal shelf rockfish	1.3	1.2	1.2	29.3	32.3	18.7
	Rockfish minus target	22.4	55.9	23.2	30.8	34.4	18.2
	Sablefish	3.2	4.0	1.2	58.9	32.0	25.9
	Pacific cod	3.4	3.6	1.5	37.8	27.6	28.7
	Walleye pollock	3.1	5.0	1.4	56.9	41.3	29.6
	Rex sole	0.7	2.8	1.4	39.0	41.9	29.8
	Flathead sole	0.5	0.4	0.0	103.1	93.8	24.4
	Arrowtooth flounder	16.5	34.8	13.2	44.3	51.5	29.2
	Deepwater flatfish	1.6	3.5	0.7	49.3	41.6	28.8
	Shallow-water flatfish	0.1	0.0	0.1	102.3	82.8	29.3
	Number of Hauls	30	28	28			
Pacific ocean perch	Northern rockfish	0.9	1.7	1.0	43.5	46.0	12.8
	Pelagic shelf rockfish	1.8	0.7	0.3	63.9	45.4	12.0
	Shortspine thornyhead	5.5	1.8	2.2	26.4	24.2	14.7
	Shortraker/roughey	1.2	1.6	1.0	34.1	33.1	14.0
	Demersal shelf rockfish	0.2	0.1	0.1	35.6	33.2	15.3
	Other slope rockfish	4.5	4.7	2.8	28.5	35.3	13.1
	Rockfish minus target	14.1	10.7	7.3	11.2	21.0	12.5
	Sablefish	6.7	9.8	3.0	44.6	39.3	12.5
	Pacific cod	5.7	3.4	2.1	30.6	32.1	13.1
	Walleye pollock	10.0	3.9	2.2	31.5	28.2	13.4
	Rex sole	4.6	1.7	1.5	36.4	24.9	13.6
	Flathead sole	0.8	0.2	0.1	45.1	61.8	15.1
	Arrowtooth flounder	36.1	23.8	8.1	45.0	34.4	13.7
	Deepwater flatfish	4.7	2.5	1.4	28.6	28.6	14.8
	Shallow-water flatfish	0.2	0.1	0.1	71.0	47.2	14.3
	Number of Hauls	73	80	95			

– continued –

Table 2. (continued)

Target Species	Bycatch Species	Bycatch Rate (%)			Coefficient of Variation (%)		
		1990	1993	1996	1990	1993	1996
Pelagic shelf rockfish	Pacific ocean perch	12.7	7.9	46.0	35.1	88.7	21.2
	Northern rockfish	6.6	33.7	42.7	40.8	45.3	30.6
	Shortspine thornyhead	0.0	0.0	0.0	120.5	118.1	63.6
	Shortraker/rougheye	0.7	0.4	1.0	100.0	101.4	28.0
	Demersal shelf rockfish	1.1	0.2	0.2	71.4	115.5	45.2
	Other slope rockfish	37.3	1.7	4.2	29.8	40.6	26.6
	Rockfish minus target	58.3	43.9	94.1	36.3	49.9	4.2
	Sablefish	0.3	1.4	6.7	76.6	87.0	29.8
	Pacific cod	4.3	4.9	15.5	44.5	37.0	28.2
	Walleye pollock	0.9	0.1	0.4	89.1	41.9	63.9
	Rex sole	1.0	1.5	1.0	69.4	80.4	29.9
	Flathead sole	0.1	0.5	0.9	123.0	46.5	48.9
	Arrowtooth flounder	5.8	61.5	50.1	77.5	71.1	56.3
	Deepwater flatfish	0.3	2.0	1.4	81.9	67.3	45.2
	Shallow-water flatfish	0.0	2.1	0.1		0.0	60.8
	Number of Hauls	7	11	7			
Shortraker/rougheye rockfish	Pacific ocean perch	4.8	3.5	4.1	37.4	51.4	22.2
	Northern rockfish	0.0	0.1	0.0	71.8	48.5	
	Pelagic shelf rockfish	0.1	0.1	0.0	79.8	66.7	
	Shortspine thornyhead	17.4	12.0	20.8	13.6	26.9	16.6
	Demersal shelf rockfish	0.0	0.0	0.0	100.6		26.1
	Other slope rockfish	0.8	0.3	0.4	47.9	65.8	25.9
	Rockfish minus target	23.1	16.0	25.2	22.6	28.0	17.4
	Sablefish	18.8	15.3	18.7	26.9	31.8	22.3
	Pacific cod	0.2	1.8	0.1	62.2	51.8	23.8
	Walleye pollock	8.1	4.5	4.2	39.2	33.4	24.8
	Rex sole	1.8	6.2	5.2	31.7	29.7	27.5
	Flathead sole	1.2	3.6	1.3	81.5	45.2	27.6
	Arrowtooth flounder	37.1	65.8	31.2	40.7	29.8	26.7
	Deepwater flatfish	11.1	10.9	11.3	19.8	32.8	24.4
	Shallow-water flatfish	0.0	0.0	0.0	75.6	85.4	23.0
	Number of Hauls	39	39	33			
Shortspine thornyhead	Pacific ocean perch	24.9	13.3	20.3	25.3	33.3	16.4
	Northern rockfish	0.0	0.2	0.1		82.9	23.4
	Pelagic shelf rockfish	0.2	0.5	0.4	93.8	80.5	22.6
	Shortraker/rougheye	30.4	34.5	28.3	34.9	20.3	18.4
	Demersal shelf rockfish	0.6	0.0	0.0	75.8		
	Other slope rockfish	14.0	1.1	1.4	63.8	39.6	23.0
	Rockfish minus target	70.1	49.7	50.5	35.3	17.1	13.5
	Sablefish	29.0	59.2	45.5	30.3	19.1	14.1
	Pacific cod	3.0	1.0	1.4	70.2	87.7	22.6
	Walleye pollock	24.5	26.9	13.9	46.6	24.3	24.8
	Rex sole	13.9	23.5	20.6	26.6	29.6	21.1
	Flathead sole	8.4	10.6	1.8	87.9	74.3	25.3
	Arrowtooth flounder	113.9	84.4	48.3	50.2	14.4	21.6
	Deepwater flatfish	47.4	53.2	34.7	26.1	23.2	21.2
	Shallow-water flatfish	0.1	0.1	0.0	101.4	71.0	23.4
	Number of Hauls	14	20	37			

Table 3. Estimated bycatch rates in Gulf of Alaska rockfish fisheries based on observer data for the entire year.

Target Species	Bycatch Species	Bycatch Rate (%)			Coefficient of Variation (%)		
		1994	1995	1996	1994	1995	1996
Northern rockfish	Pacific ocean perch	2.2	3.2	4.6	29.7	18.2	24.4
	Pelagic shelf rockfish	16.3	19.3	34.4	5.5	7.2	7.5
	Shortspine thornyhead	0.0	0.2	0.0	66.6	41.6	59.9
	Shortraker/roughey	0.1	0.1	0.2	34.2	47.6	57.3
	Demersal shelf rockfish	0.2	0.3	0.5	29.1	22.5	20.6
	Other slope rockfish	3.5	3.6	6.9	11.7	14.4	16.0
	Rockfish minus target	22.4	28.8	48.4	6.3	7.7	8.2
	Sablefish	0.3	0.4	0.4	35.0	35.7	50.1
	Pacific cod	2.0	2.1	3.7	15.9	15.2	22.8
	Walleye pollock	0.1	0.1	0.2	45.1	54.1	60.5
	Pacific halibut	0.6	1.4	2.6	21.9	24.7	15.0
	Rex sole	0.1	0.2	1.6	32.5	29.9	38.5
	Flathead sole	0.0	0.1	0.5	36.5	36.7	43.5
	Arrowtooth flounder	1.0	2.1	6.6	26.3	23.7	33.2
	Deepwater flatfish	0.1	0.1	0.2	36.5	34.1	43.6
	Shallow-water flatfish	0.1	0.1	0.2	28.3	20.6	28.2
	Number of Hauls	281	283	156			
Other slope rockfish	Pacific ocean perch	6.0	9.4	4.5	42.2	43.6	30.8
	Northern rockfish	13.7	17.0	22.7	53.3	28.1	24.7
	Pelagic shelf rockfish	51.4	39.8	50.3	19.7	21.2	18.5
	Shortspine thornyhead	0.5	0.1	0.7	51.4	61.5	65.5
	Shortraker/roughey	0.2	0.1	0.2	97.7	84.2	53.1
	Demersal shelf rockfish	20.1	1.4	2.8	44.1	39.7	60.5
	Rockfish minus target	130.6	75.6	106.2	13.6	17.6	15.7
	Sablefish	1.6	0.5	1.2	45.9	62.8	107.8
	Pacific cod	1.5	2.8	1.9	38.2	50.3	41.1
	Walleye pollock	0.5	0.3	0.4	87.7	97.1	50.5
	Pacific halibut	2.6	1.0	4.5	38.8	60.3	45.9
	Rex sole	0.2	0.4	0.7	46.6	78.0	55.6
	Flathead sole	0.0	0.2	0.0	104.7	73.5	
	Arrowtooth flounder	2.3	4.7	6.0	48.4	72.0	78.7
	Deepwater flatfish	0.3	0.2	0.2	52.7	104.3	90.6
	Shallow-water flatfish	0.0	0.0	0.0	88.5	108.8	
	Number of Hauls	41	19	16			
Pacific ocean perch	Northern rockfish	10.0	1.5	1.6	53.4	24.8	17.5
	Pelagic shelf rockfish	6.9	2.8	1.4	29.4	26.0	15.4
	Shortspine thornyhead	2.2	2.0	1.1	25.1	13.2	14.1
	Shortraker/roughey	4.2	5.3	2.1	24.9	12.8	21.4
	Demersal shelf rockfish	0.1	0.1	0.0	30.9	30.4	29.0
	Other slope rockfish	6.0	1.5	0.7	27.7	33.3	19.4
	Rockfish minus target	36.2	15.3	9.5	21.7	11.8	9.9
	Sablefish	11.5	5.0	3.8	20.1	16.2	15.2
	Pacific cod	3.8	1.6	1.9	24.1	14.9	13.0
	Walleye pollock	1.8	2.2	1.6	25.0	14.4	17.2
	Pacific halibut	4.5	3.0	1.5	22.0	21.1	14.1
	Rex sole	4.1	1.7	2.0	25.2	23.0	15.8
	Flathead sole	0.8	0.2	0.2	34.3	25.5	28.5
	Arrowtooth flounder	25.6	11.4	10.8	17.8	11.5	13.9
	Deepwater flatfish	3.0	0.5	0.6	25.7	16.1	15.5
	Shallow-water flatfish	0.1	0.0	0.1	57.4	52.0	41.8
	Number of Hauls	104	213	330			

– continued –

Table 3. (continued)

Target Species	Bycatch Species	Bycatch Rate (%)			Coefficient of Variation (%)		
		1994	1995	1996	1994	1995	1996
Pelagic shelf rockfish	Pacific ocean perch	4.6	11.1	7.4	18.2	16.5	27.5
	Northern rockfish	23.1	30.7	49.1	16.5	13.9	10.9
	Shortspine thornyhead	0.3	0.1	0.0	54.3	46.8	64.2
	Shortraker/rougheye	0.8	0.7	0.7	47.6	43.8	71.9
	Demersal shelf rockfish	2.7	1.1	0.8	22.8	23.2	24.4
	Other slope rockfish	28.1	21.4	20.2	8.9	13.6	14.6
	Rockfish minus target	85.4	76.5	87.5	8.7	9.8	9.6
	Sablefish	12.0	2.0	3.0	20.1	26.5	34.9
	Pacific cod	4.5	5.5	4.9	18.0	25.2	20.7
	Walleye pollock	0.2	0.0	0.2	32.4	49.2	55.9
	Pacific halibut	9.6	5.3	4.5	15.9	27.6	18.3
	Rex sole	1.2	1.2	1.1	20.4	47.7	39.6
	Flathead sole	0.2	0.2	0.3	49.1	65.7	55.9
	Arrowtooth flounder	10.1	6.2	4.6	32.0	21.6	32.6
	Deepwater flatfish	1.1	0.9	0.1	25.3	64.8	43.2
	Shallow-water flatfish	0.1	0.1	0.3	32.3	59.9	67.1
	Number of Hauls	131	98	73			
Shortraker/rougheye rockfish	Pacific ocean perch	4.1	11.5	8.6	37.4	26.7	20.7
	Northern rockfish	0.1	0.2	0.3	44.8	43.0	38.3
	Pelagic shelf rockfish	0.2	0.1	0.7	43.6	50.5	56.9
	Shortspine thornyhead	11.9	9.3	8.6	16.1	13.7	11.5
	Demersal shelf rockfish	0.0	0.0	0.0	100.2	101.2	52.6
	Other slope rockfish	0.2	0.1	0.3	70.6	60.0	46.5
	Rockfish minus target	17.4	22.2	24.1	17.4	17.1	14.3
	Sablefish	21.1	22.4	17.8	16.8	15.0	12.6
	Pacific cod	0.4	0.2	2.0	53.4	52.8	36.8
	Walleye pollock	0.6	1.0	1.0	33.4	35.3	38.2
	Pacific halibut	4.3	4.2	3.5	39.4	24.8	26.6
	Rex sole	1.8	2.1	1.3	22.6	22.5	24.4
	Flathead sole	0.2	0.1	0.2	53.4	42.8	62.8
	Arrowtooth flounder	42.4	43.4	29.3	23.8	17.2	23.1
	Deepwater flatfish	9.6	4.8	5.0	25.8	22.0	23.3
	Shallow-water flatfish	0.0	0.0	0.1	101.4	59.8	84.6
	Number of Hauls	89	99	97			
Shortspine thornyhead	Pacific ocean perch	8.2	23.9	20.8	41.8	26.6	34.1
	Northern rockfish	0.7	2.7	3.3	100.2	67.2	72.3
	Pelagic shelf rockfish	0.2	0.3	0.2	96.6	101.5	75.7
	Shortraker/rougheye	23.6	25.0	22.5	25.9	30.3	26.5
	Demersal shelf rockfish	0.0	0.0	0.0	103.6		
	Other slope rockfish	0.1	0.0	0.1	103.6		104.3
	Rockfish minus target	35.7	52.9	48.8	21.9	26.0	23.1
	Sablefish	48.5	29.7	29.0	9.9	23.4	26.8
	Pacific cod	0.9	1.8	4.0	47.9	69.5	54.0
	Walleye pollock	11.7	5.8	13.0	34.2	36.5	49.1
	Pacific halibut	6.1	16.2	11.4	25.7	54.5	34.8
	Rex sole	9.1	11.2	20.4	26.8	37.7	29.5
	Flathead sole	0.3	2.5	1.0	98.3	50.6	34.7
	Arrowtooth flounder	67.1	93.4	120.1	16.5	44.1	21.5
	Deepwater flatfish	18.2	38.1	31.6	21.5	26.9	27.8
	Shallow-water flatfish	0.0	0.1	0.2		101.5	52.7
	Number of Hauls	38	15	25			

Computation of Bycatch Rates

We used survey and fisheries data to estimate natural bycatch rates of NPFMC-managed species in rockfish fisheries of the Gulf of Alaska and in the Pacific ocean perch and Atka mackerel fisheries in the Aleutian Islands. Natural bycatch rates are calculated based on the species composition of the total catch from individual hauls. The natural bycatch rates are calculated as the ratio of the total incidental catch of a particular species or assemblage to the total catch of the species or assemblage that is the target of a directed fishery (as listed in Table 1).

Letting C_{ijk} equal catch of species i in haul j where species k is the target, and T_{jk} equal the catch of target species k in haul j , the bycatch rate of species i when species k is the target is

$$B_{ik} = \frac{\sum_j C_{ijk}}{\sum_j T_{jk}} = \frac{\bar{C}_{ik}}{\bar{T}_k} \quad (1)$$

The approximate variance of such a ratio estimator can be derived using the delta method (Seber 1982) to give

$$\text{Var}(B_{ik}) = \frac{1}{n_k \bar{T}_k^2} (\mathbf{s}_{T_k}^2 B_{ik}^2 + \mathbf{s}_{C_{ik}}^2 - 2\mathbf{r}_{ik} \mathbf{s}_{T_k} \mathbf{s}_{C_{ik}} B_{ik}), \quad (2)$$

where n_k is the number of hauls where species k is the target, $\mathbf{s}_{C_{ik}}^2$ and $\mathbf{s}_{T_k}^2$ are the estimated variances of C_{ik} and T_k , respectively, and \mathbf{r}_{ik} is the correlation between C_{ik} and T_k . We provide estimates of the coefficient of variation (CV) for all estimates. The CV is the standard deviation (i.e., square root of the estimated variance from Eq. 2) divided by the estimate. The CV allows comparisons of the precision of various estimates.

Analysis

Anecdotal information indicated that some rockfish fisheries operating in the Gulf of Alaska in July generally had low sablefish bycatch rates. However, some fishermen were topping off to increase the amount of sablefish in a trip to an amount approaching the MRB level, thus increasing overall sablefish harvest rates to levels that exceeded quotas. For instance, sablefish quotas in non-directed fisheries are frequently exceeded in the Central Gulf of Alaska management area (annual NMFS catch statistics are available at <http://www.fakr.noaa.gov/sustainablefisheries/>

catchstats.htm). The NMFS observer data from individual vessels operating during 1994–1996 were analyzed spatially and temporally for indications of topping off. Data from 1995 and 1996 were used in a similar analysis of hauls in the Aleutian Islands fisheries for Pacific ocean perch or Atka mackerel to assess bycatch rates and the anecdotal evidence of topping off on shortraker–rougheye rockfish. One vessel was chosen for illustrative purposes. This vessel was generally representative of the other vessels, but vessel behavior varies because each vessel is unique as to target preference, reactions to anticipated management actions, areas fished, economic decisions, vessel configuration, and other factors. Because the hauls are vessel specific, and thus confidential, only general descriptions of target preferences are presented to protect vessel identities.

A primary temporal indicator of topping-off behavior is target switching, when several hauls in succession are made for one target and then one or more are made for another target. The spatial component of target switching is revealed using a geographical information system (GIS) when several hauls under one target are made in one location and then the location and target change for a brief period. Once temporal target switching was indicated, the hauls were examined with GIS (ArcView and ARC/INFO) to see if the hauls apparently made to top off were also spatially separated from the primary target hauls. A GIS was used to display the location of each haul from all vessels, including the example vessel, and to provide indications of a spatial component to the apparent patterns in targeting. Whereas a detailed analysis was conducted on individual hauls by individual vessels, all hauls from all vessels and gear types for multiple years were combined in maps so the individual fishing behavior or specific haul locations for individual vessels remains confidential.

RESULTS

Gulf of Alaska Rockfish Fisheries

In the survey data aggregated rockfish (the total across all rockfish target categories; rockfish minus target in Table 2) was the dominant species group for 619 hauls over 3 survey years (Table 2). Of these hauls Pacific ocean perch was the target species in 40% of the hauls, followed by shortraker–rougheye rockfish (18%), other slope rockfish (14%), northern rockfish (13%), shortspine thornyheads (11%), pelagic shelf rockfish (4%), and demersal shelf rockfish (1%). Demersal shelf

Table 4. Average bycatch rates of rockfish in the Aleutian Islands Atka mackerel fishery. Rates are defined as the ratio of bycatch weight to directed species catch weight.

Bycatch Species	Area	Rate (%)		CV (%)	
		1995	1996	1995	1996
Northern rockfish	Aleutian Islands (Total)	3.13	3.81	5.11	4.08
	Eastern Aleutians	2.25	1.90	11.75	11.83
	Central Aleutians	2.58	4.08	7.78	7.38
	Western Aleutians	4.98	4.90	7.69	5.21
Pacific ocean perch	Aleutian Islands (Total)	1.17	1.43	8.77	7.04
	Eastern Aleutians	1.26	0.39	29.82	12.30
	Central Aleutians	0.98	2.17	12.58	9.68
	Western Aleutians	1.56	1.57	10.75	11.40
Pelagic slope rockfish	Aleutian Islands (Total)	0.01	0.04	25.67	48.01
	Eastern Aleutians	0.02	0.03	50.38	20.55
	Central Aleutians	0.01	0.10	32.25	62.50
	Western Aleutians	0.00	0.01	72.36	34.87
Shortraker/rougheye rockfish	Aleutian Islands (Total)	0.09	0.09	15.51	16.51
	Eastern Aleutians	0.06	0.01	54.91	34.95
	Central Aleutians	0.08	0.16	19.48	15.71
	Western Aleutians	0.12	0.10	27.99	33.01
Other rockfish	Aleutian Islands (Total)	0.01	0.01	35.57	36.38
	Eastern Aleutians	0.01	0.00	79.06	41.86
	Central Aleutians	0.02	0.01	42.57	61.80
	Western Aleutians	0.01	0.01	50.37	45.57
Total rockfish	Aleutian Islands (Total)	4.42	5.40	4.77	3.80
	Eastern Aleutians	3.60	2.34	13.49	10.06
	Central Aleutians	3.68	6.54	7.20	6.40
	Western Aleutians	6.67	6.60	6.92	5.13
Number of Hauls	Aleutian Islands (Total)	1,211	1,653		
	Eastern Aleutians	143	392		
	Central Aleutians	715	596		
	Western Aleutians	353	665		

rockfish was eliminated from further analysis as a target species because too few hauls were categorized as demersal shelf rockfish.

Arrowtooth flounders and aggregated rockfish had the highest bycatch rates over all rockfish target species and years. This was true even for the more pelagic rockfish species groups, as would be expected from bottom-survey gear. The natural bycatch rates of the various species captured in the Gulf of Alaska rockfish hauls suggested 3 general groups: (1) hauls with relatively low bycatch of flatfish and demersal species, as in the northern and other slope rockfish hauls; (2) near-bottom hauls with relatively higher bycatch rates of demersal species, as in the Pacific ocean perch and pelagic shelf rockfish hauls; and (3) hauls with high catch of bottom-dwelling species, as in hauls for shortraker and rougheye rockfish and shortspine

thornyheads. Bycatch rates of sablefish were highest when shortspine thornyheads, shortraker, and rougheye rockfish were the target species and lowest when northern rockfish was the target species. Bycatch rates of Atka mackerel, shallow-water flatfish, and demersal shelf rockfish were low ($<2.2\%$) for all target species. Most estimates of bycatch rates were reasonably precise with CVs usually $<50\%$ (Table 2). In general, high CVs were associated with low estimates of bycatch rates, which is often typical of ratio estimators.

Among the 2,108 observed rockfish hauls in the fishery data between 1994 and 1996, approximately 34% were categorized as northern rockfish hauls, 31% were categorized as Pacific ocean perch, 14% were pelagic shelf rockfish, 14% were shortraker–rougheye rockfish, 4% were other slope rockfish, and 4% were

Table 5. Average bycatch rates of rockfish in the Aleutian Islands Pacific ocean perch fishery. Rates are defined as the ratio of bycatch weight to directed species catch weight.

Bycatch Species	Area	Rate (%)		CV (%)	
		1995	1996	1995	1996
Northern rockfish	Aleutian Islands (Total)	2.75	2.46	25.25	18.55
	Eastern Aleutians	2.65	3.55	30.34	28.84
	Central Aleutians	2.09	3.77	39.19	42.39
	Western Aleutians		1.56		30.14
Pelagic slope rockfish	Aleutian Islands (Total)	0.08	0.04	25.07	32.33
	Eastern Aleutians	0.09	0.05	26.35	54.40
	Central Aleutians	0.02	0.12	72.39	38.08
	Western Aleutians		0.01		100.92
Shortraker/rougheye rockfish	Aleutian Islands (Total)	2.11	5.08	17.26	10.21
	Eastern Aleutians	2.30	3.71	20.25	25.45
	Central Aleutians	1.49	4.78	21.15	22.81
	Western Aleutians		5.85		12.59
Shortspine thornyhead	Aleutian Islands (Total)	0.04	0.25	31.70	18.10
	Eastern Aleutians	0.02	0.00	37.55	101.85
	Central Aleutians	0.12	0.17	45.72	39.90
	Western Aleutians		0.39		18.70
Other rockfish	Aleutian Islands (Total)	0.09	0.02	93.33	43.33
	Eastern Aleutians	0.12	0.00	97.46	
	Central Aleutians	0.02	0.10	97.11	50.98
	Western Aleutians		0.01		62.56
Total rockfish (without Pacific ocean perch)	Aleutian Islands (Total)	5.09	7.89	15.46	8.89
	Eastern Aleutians	5.19	7.37	17.48	18.64
	Central Aleutians	3.75	8.94	24.89	21.89
	Western Aleutians		7.86		11.27
Number of Hauls	Aleutian Islands (Total)	210	248		
	Eastern Aleutians	142	72		
	Central Aleutians	59	46		
	Western Aleutians	9	130		

shortspine thornyheads. Pacific ocean perch was a bycatch-only species in the Gulf of Alaska in 1994 with the exception of an Eastern Gulf area opening in late 1994. Directed fishing for Pacific ocean perch in 1995 began on July 3 and closed in the Central Gulf area on July 6, in the Eastern Gulf area on July 9, and in the Western Gulf area on July 20. Directed fishing for Pacific ocean perch in 1996 was closed for all areas on July 11. The increase in number of hauls within the Pacific ocean perch target is evident in Table 3 (from 104 hauls in 1994 to 330 hauls in 1996). Similarly, the observed catch of Pacific ocean perch when it was the target increased dramatically between 1994 and 1996 from approximately 200 metric tons observed in 1994 to 2,700 tons observed in 1995 and 3,400 tons in 1996. The catch of Pacific ocean perch in each year

was primarily in hauls classified as Pacific ocean perch hauls due to the dominance of that species in the catch.

Bycatch rates of a species across years generally were similar within the various rockfish fisheries and generally were higher for rockfish species than for non-rockfish species. Similar to the survey results, the bycatch rates for Atka mackerel, shallow-water flatfish, demersal shelf rockfish, and flathead sole were low for all rockfish target species, and nearly all hauls with a bycatch rate > 5% had CVs < 50%.

As with the survey results, the bycatch rates of sablefish were highest when shortspine thornyheads and shortraker-rougheye rockfish were the target species and lowest when northern rockfish was the target. Observed sablefish bycatch rates in hauls targeting Pacific ocean perch were highest in 1994 when there was no directed fishery for Pacific ocean perch (11.5%),

July 1994

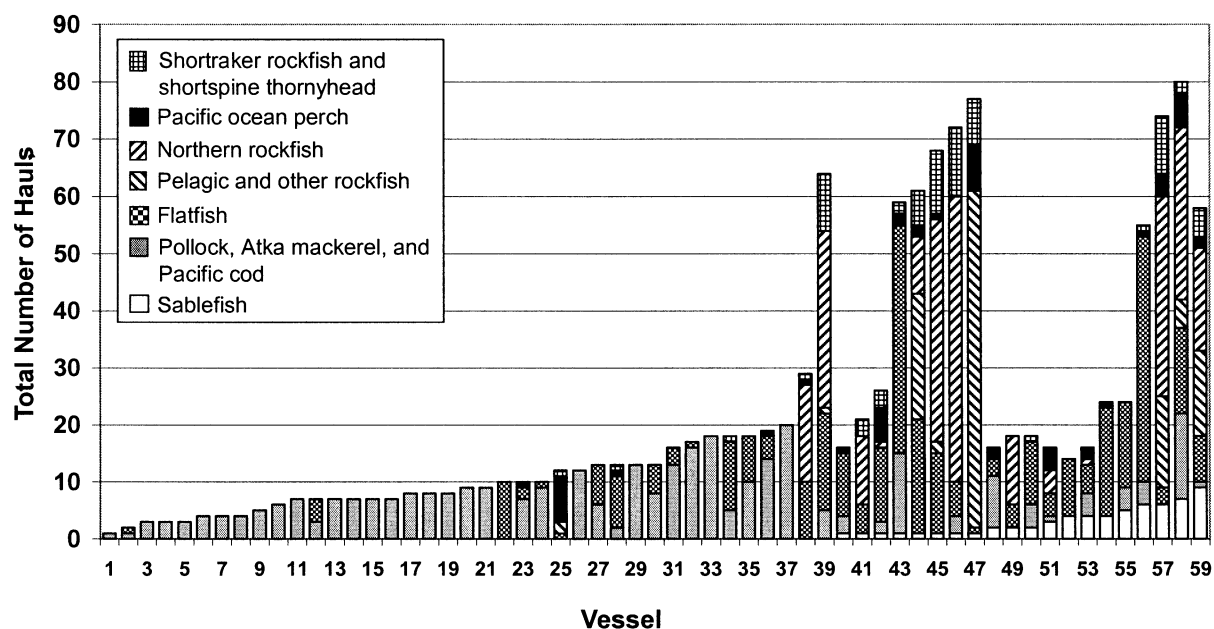


Figure 1. Numbers of observed hauls for vessels fishing in Gulf of Alaska rockfish fisheries, July 1994. Histobars are partitioned by dominant catch species (target), by weight, and sorted by increasing number of sablefish hauls and increasing total number of hauls.

July 1995

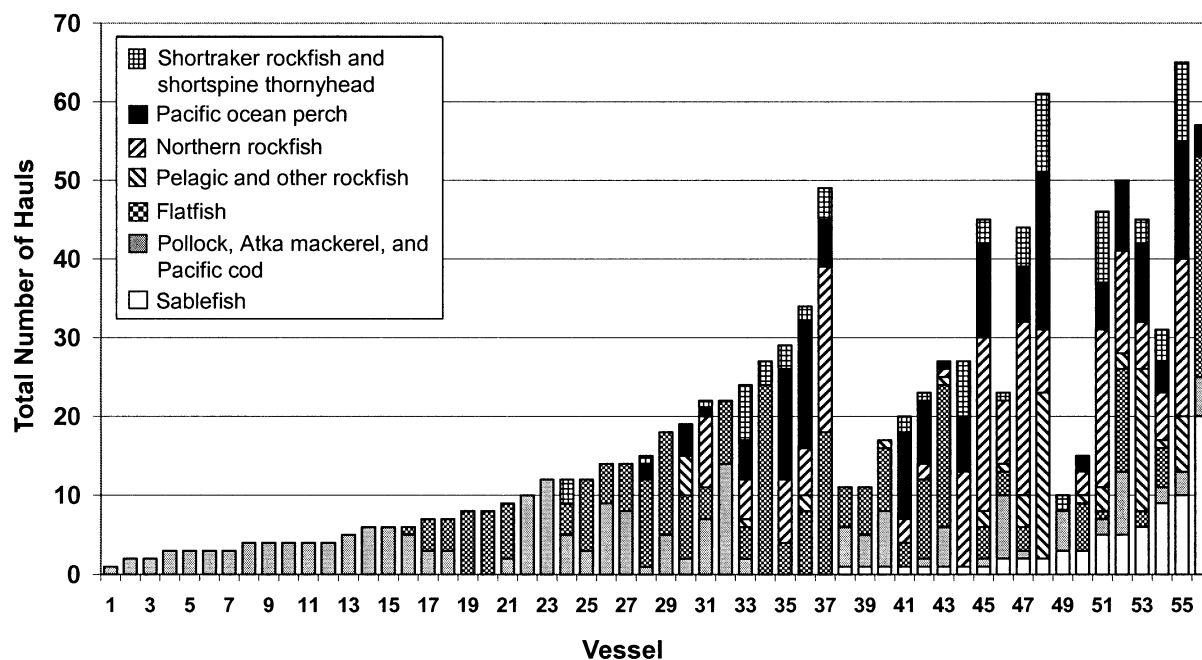


Figure 2. Numbers of observed hauls for vessels fishing in Gulf of Alaska rockfish fisheries, July 1995. Histobars are partitioned by dominant catch species (target), by weight, and sorted by increasing number of sablefish hauls and increasing total number of hauls.

and the rates were lower in 1995 (5.0%) and in 1996 (3.8%) when most of the observed hauls were made during directed Pacific ocean perch fisheries. The MRB rate for sablefish in rockfish fisheries was 15% in 1994, and 7% in 1997.

Aleutian Islands Atka Mackerel and Pacific Ocean Perch Fisheries

The overall observed fishery bycatch rates of various rockfish species in the Aleutian Islands are provided in Table 4 for the Atka mackerel fishery and in Table 5 for the Pacific ocean perch fishery. The overall natural rate of shortraker–rougheye rockfish bycatch in the Atka mackerel fishery was 0.09% in both 1995 and 1996 (Table 4). The overall rate of aggregated rockfish bycatch in this fishery was 4.42% and 5.40% in 1995 and 1996, respectively, approximately the established MRB rate of 5%. The MRB for rockfish applies to the catch of all rockfish species combined. Within the Aleutian Islands, the eastern portion (NMFS statistical area 541) had the lowest bycatch rates of shortraker–rougheye rockfish (0.06% in 1995 and

0.01% in 1996) and aggregated rockfish (3.60% in 1995 and 2.34% in 1996) in the Atka mackerel fishery. The western Aleutian Islands (NMFS statistical area 543) generally had the highest rates with 0.12% for shortraker–rougheye rockfish in 1995, and 6.67% and 6.60% for aggregated rockfish in 1995 and 1996, respectively. Similar rates occurred in the central Aleutian Islands (NMFS statistical area 542) in 1996. The primary rockfish bycatch species in the Atka mackerel fishery was northern rockfish.

The bycatch rate of shortraker–rougheye rockfish in the Pacific ocean perch fishery more than doubled between 1995 and 1996 (Table 5). The 1995 bycatch rate was 2.11%, and the 1996 bycatch rate was 5.08%. Although similar to the bycatch rate for northern rockfish in 1995 (2.75%), shortraker–rougheye was the rockfish group caught at the highest rate in 1996. The overall bycatch rate for aggregated rockfish bycatch in the Pacific ocean perch fishery was 5.09% in 1995 and 7.89% in 1996. The eastern Aleutian Islands had the highest bycatch rates for shortraker–rougheye rockfish (2.30%) and aggregated rockfish bycatch (5.19%) in 1995. The TAC for Pacific ocean perch in the Aleu-

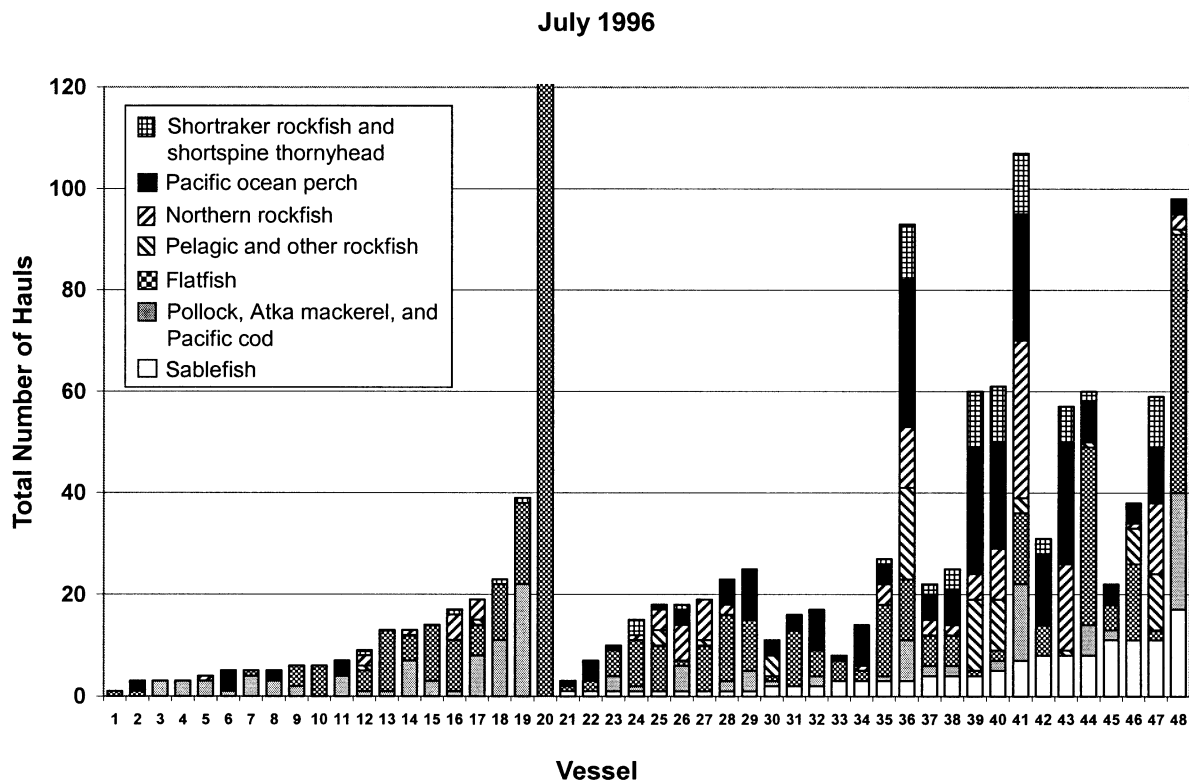


Figure 3. Numbers of observed hauls for vessels fishing in Gulf of Alaska rockfish fisheries, July 1996. Histobars are partitioned by dominant catch species (target), by weight, and sorted by increasing number of sablefish hauls and increasing total number of hauls.

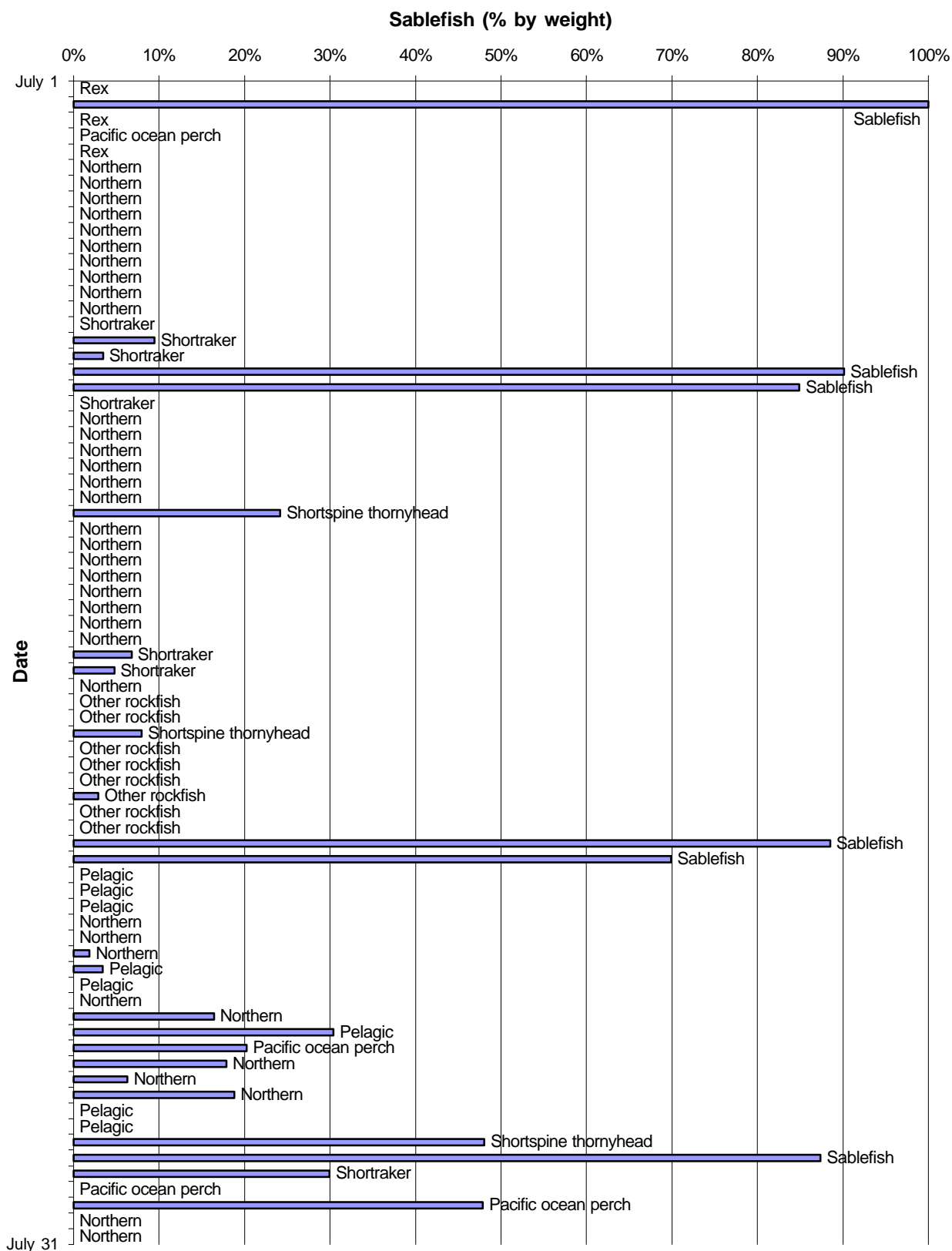


Figure 4. Percent weight of sablefish in sequential hauls by a single vessel with dominant species target of each haul identified. Hauls were made in the Gulf of Alaska in July 1994.

tian Islands in 1995 was areawide, but catch was concentrated in the eastern portion, with very little effort (9 observed hauls) in the western Aleutians. In 1996 the TAC was divided by areas, with 50% of the TAC designated for the western Aleutian Islands and 25% of the TAC each for the central and eastern Aleutian Islands, respectively. The bycatch rate for shorttraker-rougeye rockfish in 1996 increased from east to west and was 3.71% in the eastern area, 4.78% in the central area, and 5.85% in the western area. In contrast,

the aggregated rockfish bycatch was highest in the central Aleutian Islands (8.94%).

Sablefish Bycatch in the Gulf of Alaska Rockfish Fisheries

The primary fishing period for rockfish in the Gulf of Alaska is during July. The directed sablefish fishery was closed during this period, but sablefish was available under MRB limits. Vessel fishing patterns in July

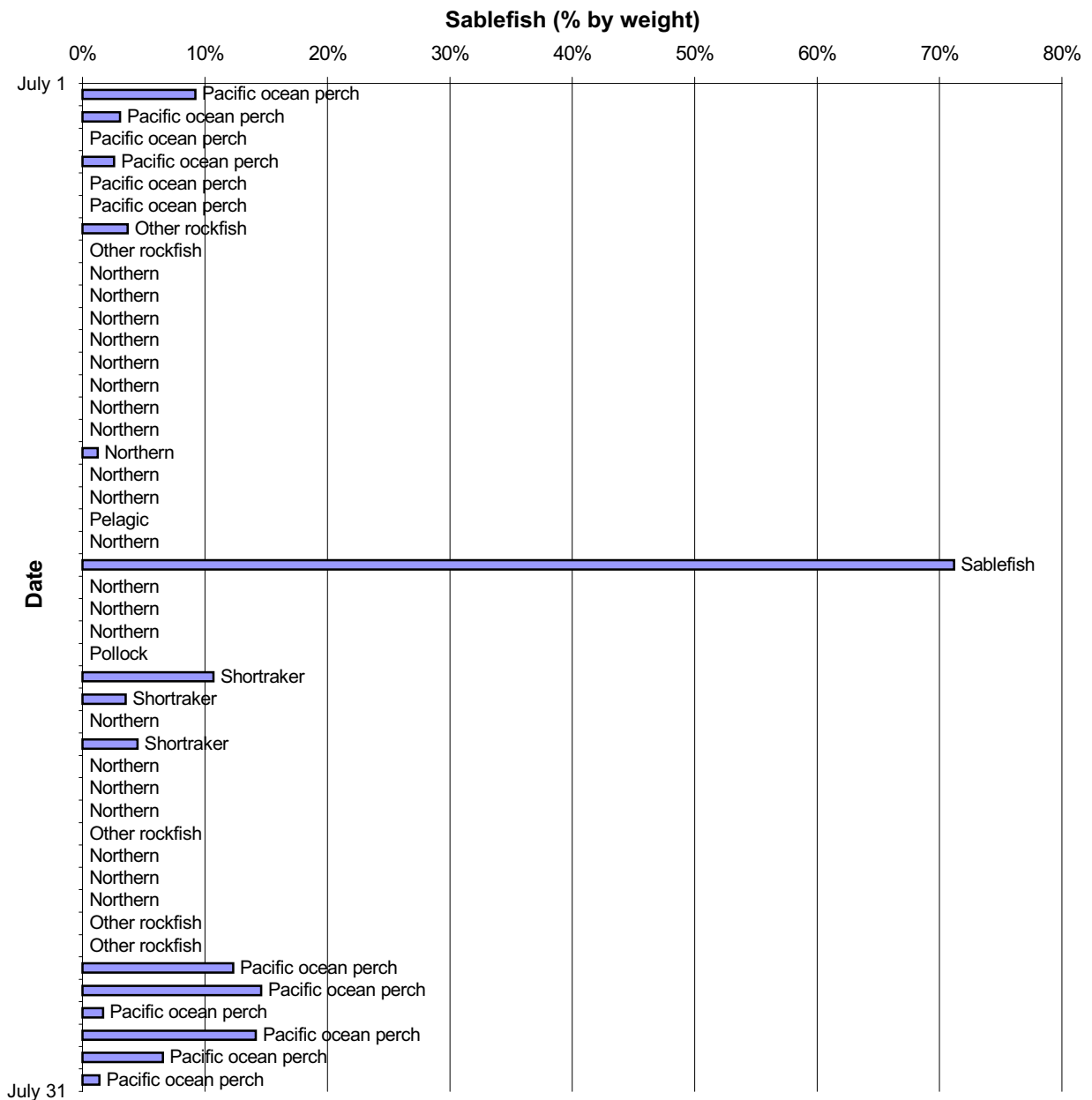


Figure 5. Percent weight of sablefish in sequential hauls by a single vessel with dominant species target of each haul identified. Hauls were made in the Gulf of Alaska in July 1995.

as a sablefish target. Similarly, 56 vessels were observed in July 1995 with 25 vessels having at least one sablefish haul, and 48 vessels were observed in 1996 with 28 vessels having at least one sablefish haul. Among the many vessels with hauls targeting sablefish in July, those with the greatest number of total hauls generally

